

§58. Evaluation of Energetic Particle Confinement Using CXNPA Diagnostics on LHD

Osakabe, M., Murakami, S. (Dept. of Nucl. Engin., Kyoto Univ.), Seki, T., Takeiri, Y., Sasao, M. (Dept. of Quan. Sci. and Energy Engin., Tohoku Univ.), LHD Experimental Group

Confinement of energetic particles is one of the most important issues in helical devices since a large helical ripple has a significant influence on the topology of energetic particle orbits. On the Large Helical Device(LHD), a series of experiments with a short pulse(blip) of tangential neutral beam(NB) injection was performed to investigate the confinement property of energetic particles during their slowing-down processes. The NB-blipped particles are measured by a tangential E/B-type CX neutral particle analyzer (NPA), which is placed to the position so that it observes the particles on their birth orbits.

New experimental technique was developed to analyze the CX-NPA data of NB-blip experiments[1]. In this method, the waveform of the neutral flux at E_i , which is associated with the NB-blip injection, is assumed to be written as;

$$\psi_i(t) = \int_{\tau_{min}}^{\tau_{max}} w_i(\tau_i) R_0(t - \tau_i) d\tau_i \quad (1),$$

where $R_0(t)$ is a response function, which is defined as $R_0(t) \equiv \psi_0(t)/\alpha$ with the wave form of the neutral flux at the beam injection energy $\psi_0(t)$ and a normalized parameter α . The $\tau_i(\rho)$ expresses the characteristic time of energy slowing-down from the injection energy(E_0) to the energy of E_i . The τ_{min} and τ_{max} are the minimum and the maximum of τ on the NPA sight line. The $w(\tau(\rho))$ is a product of the density of bulk neutrals($n_b(\rho)$), the density of energetic particle($n_e(\rho)$), the charge exchange reaction rate($\sigma_{cx,v}$) and the reionization loss effect of escaping neutrals($\exp(-(\sigma_{cx} + \sigma_{ion}) \int_{edge} n_i dl')$). In those quantities, only the density of energetic particles is unknown variables when the bulk

plasma is in quasi-steady state condition. The rest are constant in time or can be evaluated from plasma parameters. Therefore, the confinement ratio of energetic particles ($n_e(\rho)/n_b(\rho)$) can be obtained from the ratio $w_i(\rho)/w_0(\rho)$ with the correction of charge exchange reaction rate and reionization loss effect of escaping neutrals. The deconvolution method of Eq.(1) based on the maximum entropy and maximum likelihood method are shown in ref[1]. To treat the deconvolution of Eq.(1) numerically, the time range $[\tau_{min}, \tau_{max}]$ is divided into n-regions and Eq.(1) was modified as;

$$\begin{aligned} \psi_i(t) &= \sum_{j=1}^n \int_{\tau_{ij}-\Delta\tau/2}^{\tau_{ij}+\Delta\tau/2} w_i(\rho(\tau_{ij})) R_0(t - \tau_{ij}) d\tau_i \\ &\equiv \sum_{j=1}^n w_i(\rho(\tau_{ij})) R_0(t - \tau_{ij}) \Delta\tau = \sum_{j=1}^n w_{ij} R_j(t) \quad \dots(1)', \end{aligned}$$

where $R_j(t) \equiv R_0(t - \tau_{ij}) \Delta\tau$ and $w_{ij} \equiv w_i(\rho(\tau_{ij}))$. Figure 1(a) show the plots of (τ_{ij}, w_{ij}) for each spatial region. The w_{ij} is corrected by the charge exchange reaction rate and the reionization loss effect of escaping neutrals. The energetic particle confinement times are evaluated from the exponential fitting to these plots and are shown in Fig.1(b).

In Fig.2, the confinement times of energetic particles($\tau_{exp.}$), which were evaluated from NB-blip experiments, are compared to the 90-degree pitch-angle scattering time($\tau_{perp.}$) and charge exchange loss time($\tau_{cx.}$) for LHD-plasmas of $R_{ax}=3.6[m]$ and $B_t=2.5[T]$. The $\tau_{cx.}$ and $\tau_{perp.}$ are calculated from plasma parameters of the discharges and are averaged along the orbit of the energetic particles which are circulating on the NPA sight line. In Fig.2, the confinement times of energetic particles have good correlation with the pitch-angle scattering times at the core region, i.e. $r/a \leq 0.83$, and with the charge exchange loss time at the edge ($r/a=0.95$). This result indicates the confinement times of tangential energetic particles are explained by the classical theory with orbit effect at high magnetic field configurations.

Reference

1) M.Osakabe, NIFS annual report (2004)

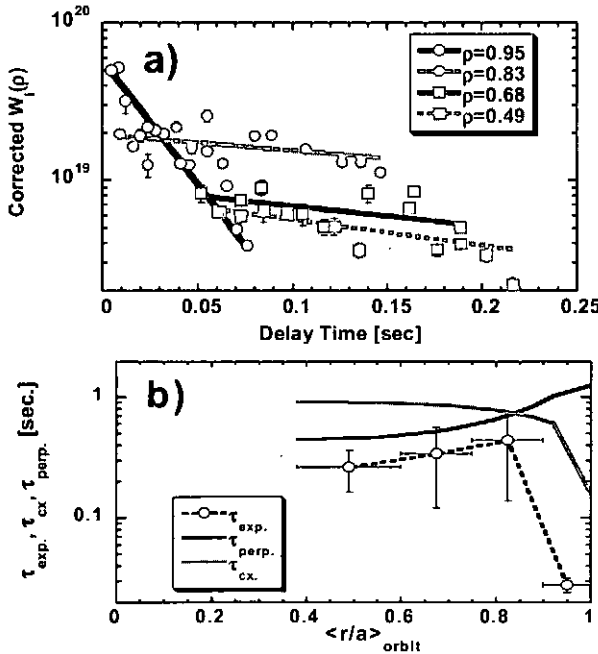


Fig.1 (a) The plots of (τ_i, w_i) for each spatial region. The exponential fitting of these plots are shown by lines in the figure. (b) The profile of the evaluated confinement times of energetic particles($\tau_{exp.}$), the calculated 90-degree pitch-angle scattering time($\tau_{perp.}$), and the charge exchange-loss time($\tau_{cx.}$). The $\tau_{perp.}$ and $\tau_{cx.}$ are averaged over the particle orbits on the NPA sight line. The energies of the particles are set to 100-keV in the calculation.

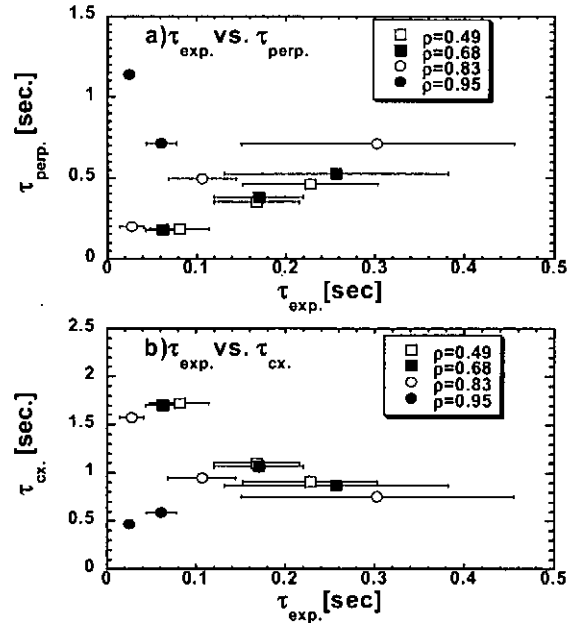


Fig. 2 Correlations of particle confinement time($\tau_{exp.}$) to (a) the 90-degree pitch-angle scattering time($\tau_{perp.}$) and to (b) the charge exchange loss time($\tau_{cx.}$) for LHD plasmas of $R_{ax}=3.6[m]$ and $B_t=2.5[T]$ configuration. In evaluating the pitch angle scattering time and charge exchange loss time, the particle energy of 100keV is assumed. The neutral density profile is obtained from AURORA code.